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Effect of Orthotics on Postural Sway After Fatigue of the Plantar Flexors and Dorsiflexors

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Objective: To examine the effects of orthotic intervention on unilateral postural sway after fatigue of the plantar flexor and dorsiflexor muscle groups.

Design and Setting: Subjects were assigned to both orthotic and nonorthotic testing conditions in a counterbalanced order, then assessed for postural sway before and after isokinetic fatiguing contractions of the plantar flexors and dorsiflexors. Postural stability was measured on the motor-dominant extremity. (Motor dominance was assessed as the foot the subject used to kick a ball.)

Subjects: Eleven active, healthy male subjects (mean age = 24 ± 2.0 years, wt = 74.5 ± 8.8 kg, ht = 180.3 ± 8.4 cm) volunteered to participate in the study.

Measurements: Center-of-pressure postural sway was assessed via the force platforms of a Chattecx Dynamic Balance System and transformed via 4 transducers as values indicative of sway in the anterior-posterior and medial-lateral directions. The dependent measure was postural sway in centimeters. Fatigue was induced by consecutive concentric plantar flexion-dorsiflexion contractions on a Kin-Com II isokinetic dynamometer.

Results: A repeated-measures analysis of variance revealed a significant orthotic-by-test interaction. Post hoc analysis with the Tukey honestly significant difference method revealed that postural sway values of the postfatigue nonorthotic condition were significantly greater when compared with the prefatigue orthotic, prefatigue nonorthotic, and postfatigue orthotic conditions.

Conclusions: Our results suggest that molded orthotics may be an effective means of decreasing postural sway after an isokinetic fatigue protocol. Further research is needed to determine the exact mechanism of this improvement and whether orthotics are an effective means of preventing ankle injury.

Key Words: balance, postural stability, isokinetic dynamometry

A growing number of studies are focusing on postural sway as it relates to injury and stability of the ankle joint.[1–8] This recent focus is due to an increasing awareness of the importance of proprioception in return to functional activity after injury, as well as its role in athletic performance,[9–13] and interest in pathologic postural sway as a predisposing factor to ankle injury.[8]

The ability to maintain the body's center of mass with minimal deviation requires the coordinated activation of joint, muscle, visual, and vestibular receptors. Investigators have attempted to evaluate gross changes in proprioception via postural sway assessment. For example, Lentell et al[4] examined the role of muscular function on postural control in individuals with unilateral ankle instability. They found no significant difference in peak torque values between the involved and uninvolved ankles and no relationship between peak torque values and postural stability as assessed with a Romberg test. However, Konradsen and Raven[3] found a significant difference in the reaction time of the peroneus brevis and longus after sudden inversion movements when stable and unstable ankles were compared. Correlation between postural sway (as measured via forceplate) and peroneal reaction time was high (Spearman $\rho = 0.92$).[3] Lundin et al[5] examined the effects of plantar and dorsiflexor fatigue on unilateral postural control. The fatigue protocol resulted in a significant increase in medial-lateral postural sway amplitude and an increase in anterior-posterior postural sway. They speculated that, if the forces required for the correction of an unstable placement of the foot are delayed due to fatigue, then the ankle joint is at risk for injury and that the differences found in their study might be the result of proprioceptive deficits. Tropp et al[8] found that individuals with "pathological" sway amplitudes were predisposed to injury in the following season.

Several studies have addressed the abnormal foot and ankle mechanics that accompany foot pathologies.[14–17] Orthotic devices have been shown to successfully modify selected aspects of lower extremity mechanics, as well as improve balance in individuals with acute ankle sprains.[1,6,14–16] Orthotics have been shown to improve postural sway when prescribed for injured populations, but results in uninjured subjects have been inconclusive, suggesting that orthotics increase structural support, improve joint congruency (which may improve proprioceptive and kinesthetic awareness), decrease stress to the

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soft or bony structures, and enhance tactile stimulation to the surface of the foot, thus decreasing postural sway.[1,6] Lundin et al[5] suggested that fatigue may adversely affect postural stability. However, it remains to be seen whether orthotic intervention can affect postural stability in the fatigued, uninjured individual.

The purpose of our study was to determine the effect of orthotics on postural sway after fatigue of the plantar flexors and dorsiflexors. We hypothesized that postural stability would improve after orthotic intervention due to neutral alignment of the subtalar joint and the increased tactile stimulation of the orthotic.

METHODS

Subjects

Eleven active males (age = 24 ± 2.0 years, wt = 74.5 ± 8.8 kg, ht = 180.3 ± 8.4 cm) volunteered to participate in the study. Subjects were eligible to participate if they had no history of injury to the lower extremity within the past year, no previous surgery, no visual or vestibular problems, and no previous use of orthotics. Before participating, subjects read and signed a university-approved human consent form. The study was approved by the University of Virginia's institutional review board.

Orthotic Construction

Before testing, subjects reported to be fit for a pair of custom orthotics using foam impression trays (Foot Management, Inc, Pittsville, MD). The subjects were seated, and the foot was placed on a foam casting block with the hip, knee, and ankle at 90° angles and the foot in a subtalar joint neutral position. The subject pressed his heel approximately 5.1 cm into the foam while the examiner's hand maintained a neutral position at the subtalar joint. The examiner's other hand pressed the remainder of the foot into the foam to the same depth as the heel. This procedure was repeated for the contralateral foot, and the negative impressions were sent to the manufacturer for fabrication of a pair of semirigid orthotics. The manufacturer was instructed to correct for any malalignments or abnormalities revealed by the impressions.

Testing Procedures

Subjects reported for testing on 2 separate occasions. On the first occasion, subjects' postural stability was assessed with or without orthotics (sequentially and alternately), before and after fatiguing contractions. On the second testing occasion, subjects were tested under the opposite condition. Subjects wore the same shoes for all testing occasions, and all testing was performed with the foot the subject used to kick a ball. After the orthotics were applied, subjects were allowed a 20-minute acclimatization period before testing.

Fatigue protocol. A Kin-Com II isokinetic dynamometer (Chattanooga Corp, Hixson, TN) was used to simultaneously fatigue the subjects' plantar flexors and dorsiflexors. Subjects were positioned on the Kin-Com II in a supine position with the hip and knee flexed to approximately 45°. The axis of rotation of the Kin-Com II dynamometer was aligned with the medial and lateral malleolus at the ankle, and the foot was secured with straps around the ankle and toes. For additional stabilization, a hook-and-loop strap was placed across the subject's waist. Subjects were instructed to keep their arms folded across their chests during testing. The warm-up and familiarization period consisted of 3 submaximal and 3 maximal concentric plantar flexion-dorsiflexion contractions. The speed of contraction was 30°/s for plantar flexion and 120°/s for dorsiflexion. We found during pilot testing that the dorsiflexors fatigued much more easily than the plantar flexors. Therefore, we chose a test speed that was less for the plantar flexors and more for the dorsiflexors to maximally fatigue the plantar flexors without exhausting the smaller and weaker dorsiflexor muscle group. The contractions occurred through a controlled range of motion of 10° of dorsiflexion to 25° of plantar flexion. After familiarization, subjects performed 3 maximal voluntary concentric contractions (MVCCs) in the plantar-flexion motion at 30°/s and 3 maximal contractions in the dorsiflexion motion at 120°/s. The highest recorded peak torque value for plantar flexion was recorded as the MVCC, and 50% of this value was used as the measure of fatigue. A 2- to 3-minute rest period was given before the fatiguing contractions were initiated.

For the fatigue protocol, subjects were instructed again to "push down and pull back with the foot as hard as possible until told to stop." Subjects were told to stop when the generated force fell below 50% MVCC for at least 3 consecutive plantar-flexion contractions. Immediately after inducement of fatigue, subjects were placed on the Chattecx Dynamic Balance System (CDBS) (Chattanooga Corp) for unilateral postural-sway assessment. The same procedure was repeated on the second day for the opposite testing condition, with at least 1 week between testing sessions. The amount of time from the end of the fatiguing protocol to the beginning of the postural sway assessment was no greater than 60 seconds.

Postural sway assessment. The CDBS was used to assess postural sway. Postural sway was measured as the distance (in centimeters) that the individuals swayed in the medial-lateral and anterior-posterior directions. The sway index produced by the machine reflects the degree of data scatter about a subject's center of balance. The data from the force-platform measurements were interfaced with software that filters and samples the data at approximately 15 cycles per second, and the sway index was calculated by determining the distance from the subject's center of balance for each of the data points. The intertester reliability of this system has been previously reported,[18] with intraclass correlation coefficients ranging from 0.41 to 0.90 during single-leg static and dynamic conditions.

To reduce any potential recovery from fatigue, positioning of each subject on the CDBS occurred before the fatigue protocol, and these settings were maintained to expedite postural assessment immediately after fatigue. Additionally, 2 25-second warm-up and familiarization trials were performed before fatigue to help control for any learning effect. During testing, the subject's dominant foot was centered on the forceplate according to the prefatigue set-up, and a harness was strapped around each subject's waist to prevent him from falling. The subjects were positioned in a unilateral stance with the weightbearing extremity slightly flexed at the hip and knee joints. The nonweightbearing extremity was placed in a neutral hip position with the knee flexed to approximately 45°. Subjects were instructed not to touch the weightbearing extremity with the opposite leg, to keep their eyes open and focused on a spot on the wall, and to let their arms relax at their sides. Testing duration was 25 seconds on a stable platform.

Subjects were instructed to maintain single-limb stance while attempting to remain as stable as possible during the test.

Statistical Analysis

We used a 1 × 3 repeated measures (between factor: subject; within factors: orthotic, test, and plane) analysis of variance (ANOVA) to analyze the data. All statistics were generated with the Statistical Package for the Social Sciences (version 6.1; SPSS Inc, Chicago, IL). We employed the Tukey honestly significant difference (HSD) post hoc analysis to examine any significant results. An a priori α level of $P < .05$ was set.

RESULTS

The means and standard deviations for all postural sway measurements are presented in Table 1. The ANOVA revealed a significant orthotic-by-test interaction ($F_{1,10} = 7.67, P < .05$) (Table 2). Post hoc analysis with the Tukey HSD method revealed that postural-sway values for postfatigue nonorthotic condition were significantly greater when compared with the prefatigue orthotic, prefatigue nonorthotic, and postfatigue orthotic conditions (Figure).

DISCUSSION

Our major finding was that, after fatiguing contractions of the plantar-flexor and dorsiflexor muscle groups, combined postural-sway values were significantly less for the orthotic conditions, both prefatigue and postfatigue (3.27 cm and 3.48 cm, respectively) than for the nonorthotic postfatigue condition (4.51 cm). Without orthotics, postfatigue postural-sway values were 1.24 and 1.03 cm higher than for the orthotic prefatigue and postfatigue conditions, respectively. In addition, there was a significant difference in postural-sway values between the prefatigue and postfatigue nonorthotic conditions, but not the orthotic conditions. It appears that the use of orthotics after isokinetically induced fatigue reduced postural sway. These results suggest that, with fatigue, the ability of the lower leg musculature to control sway becomes compromised, and molded orthotics may provide additional support. We speculate that orthotics may add structural support to the sides of the foot or improve alignment to enhance mechanical stability at the ankle mortise. Improved alignment may also be an important factor in terms of joint mechanoreceptor function and neural feedback.

To our knowledge, the effects of orthotics on postural sway in healthy, fatigued individuals have not been examined. Previous research has examined the effects of orthotics on postural sway in individuals with acute ankle sprains. Guskiewicz and Perrin[1] reported that orthotics reduced postural sway in individuals with acute ankle sprains but had no effect on uninjured individuals. This finding differs from our results. One reason for the difference may be the duration of the stability test. Guskiewicz and Perrin[1] tested for 10-second periods, versus 25-second periods in our study. They proposed that orthotics may improve alignment and relieve excessive strain on injured ankle ligaments and, thus, enhance joint mechanoreceptor function, reducing postural sway. They also speculated that orthotics may provide structural support to the sides of the foot or tactile stimulation to the bottom of the foot. Although the patients in our study were uninjured, these proposed mechanisms are all possible explanations for the postural-sway improvements we saw.

Orteza et al[6] also found that orthotic intervention improved balance in subjects with acute ankle sprains and decreased pain levels with jogging. However, they found no effect on uninjured individuals, which differs from our results. The ability to discern differences in an uninjured sample in our study may be attributed to a more sensitive measuring device. Orteza et al[6] measured postural sway using a single-axis digital balance evaluator that assessed the time out of balance and the number of times balance was lost. We measured postural sway with an instrument (CDBS) that measured vertical reaction forces using 4 force transducers. Subjects in our study were uninjured; therefore, within the limits of our study, we suggest that the increase in postural sway was due to a decline in the force-generating capacity of the plantar-flexor and dorsiflexor muscle groups.

Muscle receptors have been described as a prominent if not primary determinant of joint position sense.[19] Decreases in unilateral and bilateral balance after fatiguing contractions of the lower extremity have been attributed to muscle spindle or Golgi tendon desensitization.[20] Continued and intense stress to the muscular motor unit results in fatigue, which may be central or peripheral in origin.[21] Central fatigue is associated with reduced recruitment of new motor units or decreased firing frequency of the active units, or both. Peripheral fatigue results from a decrease in the efficiency of the contractile units of the muscle.[21] One limitation to our study was that the only measures of central and peripheral fatigue were reductions in muscular force and balance performance. We speculate that improved performance with the orthotic condition may be due to mechanical stability of the talocrural joint.

The cradling effect of the orthotic improves alignment of the talocrural joint and places the ankle mortise in a more neutral position. Neutral positioning places the muscle spindles in a position of decreased stretch and activity. Therefore, the fatigued muscle spindles are not challenged. Application of the orthotic results in increased tactile pressure to the bottom of the foot. The increased area of stimulation or increase in the receptive field might theoretically result in increased activation of nearby parent afferent fibers.[22] Our findings are

Table 1. Postural-Sway Measurements for Medial-Lateral and Anterior-Posterior Directions for the No-Orthotics and Orthotics Conditions*

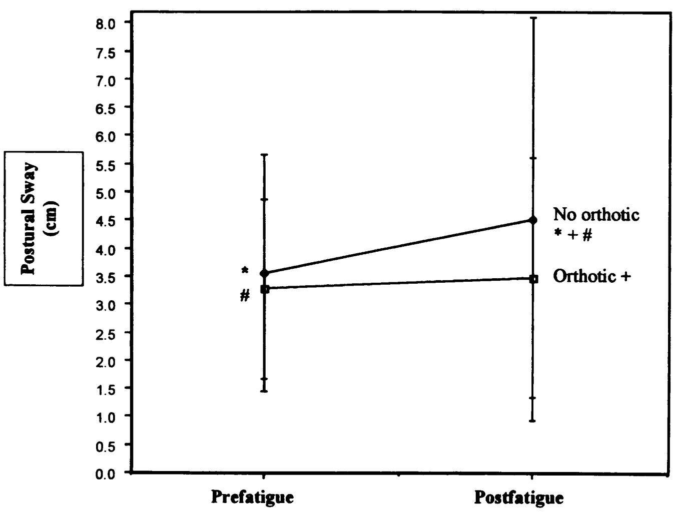
	Medial-Lateral		Anterior-Posterior		Combined†	
	Prefatigue	Postfatigue	Prefatigue	Postfatigue	Prefatigue	Postfatigue
No orthotics	2.44 (1.28)	2.89 (1.64)	4.66 (2.21)	6.13 (4.28)	3.55 (2.10)	4.51 (3.57)
Orthotics	2.32 (0.77)	2.38 (0.42)	4.22 (1.66)	4.57 (2.58)	3.27 (1.59)	3.48 (2.13)

*Mean values are expressed in centimeters (SD).
†Medial-lateral and anterior-posterior combined.

Table 2. Summary Table for the ANOVA

Source of Variance	SS*	df†	MS‡	F	Significance
Orthotic	9.47	1	9.47	1.82	.207
Error	52.07	10	5.21		
Test	7.48	1	7.48	1.14	.311
Error	65.64	10	6.56		
Plane	125.79	1	125.79	34.57	.000§
Error	36.39	10	3.64		
Orthotic × test	3.10	1	3.10	7.67	.020§
Error	4.04	10	.40		
Orthotic × plane	2.59	1	2.59	4.24	.067
Error	6.13	10	.61		
Test × plane	2.37	1	2.37	.62	.451
Error	38.52	10	3.85		
Orthotic × test × plane	.73	1	.73	2.18	.171
Error	3.36	10	.34		

*SS, sums of squares.
†df, degrees of freedom.
‡MS, mean square.
§Significant at $P < .05$.



• * + # indicate significant differences ($P < .05$) among like terms.

The orthotic × test interaction. There were 2 levels for the Orthotic factor (Orthotic and No orthotic) and 2 levels for the fatigue factor (Prefatigue and Postfatigue).

consistent with Orteza et al,[6] who suggested that improved alignment at the mortise may account for better stability. Even though the force-generating capacity of the plantar-flexor and dorsiflexor muscle groups was reduced, there was no resulting decrease in postural sway for the orthotic condition. We theorize that maintenance of a more neutral position of the subtalar joint may decrease reliance on the supporting musculature.

Induction of fatigue to the lower extremity musculature has been established with isokinetic dynamometry. Lundin et al[5] found a significant increase in postural sway after a protocol in which the subjects maximally assisted and resisted concentric-eccentric plantar-flexion and dorsiflexion contractions. Although we used a different fatiguing protocol, isokinetic-induced fatigue of the plantar flexors and dorsiflexors increased postural sway in an uninjured group of subjects. While performing the fatiguing contractions on an isokinetic dynamometer serves as an accepted and established clinical model, it remains to be seen whether postural-sway values will be compromised after a more functional and sport-specific fatigue protocol. We agree with Lundin et al[5] that, as the ankle musculature becomes fatigued, its ability to control the joint is compromised, which may be due to fatigue-induced proprioceptive deficits.

Tropp et al[8] examined athletes with a history of ankle sprains to see whether a disturbance in proprioception had an effect on functional status or predisposition to future injury. They found that subjects with large postural-sway amplitudes were especially susceptible to ankle injury in the following season. If fatigue does indeed increase postural sway, we could speculate that subjects are predisposed to ankle injury, but more research is needed in this area.

A limitation with our study was that our sample size was small ($n = 11$). This was a practical limitation, since we were able to secure funding for the fabrication of 12 pairs of orthotics, and 1 subject withdrew for personal reasons. Although our sample size was small, there was a significant test-by-orthotic interaction. Our postanalysis value for the test-by-orthotic interaction had a power of 0.70. The differences that were apparent with the orthotic application need further investigation to determine the clinical relevance of our results in a more functional environment. Therefore, although encouraging, the differences we found are not generalizable to all conditions in which balance may be compromised by muscular fatigue.

In summary, our results show that orthotics may reduce postural sway and, we believe, may prevent injuries in later stages of sport activity. Future research should address a more functional fatigue protocol, as well as postural-sway assessment under dynamic platform conditions. Additional research is also needed to determine whether orthotics have a role in injury prevention. Due to the small sample size of this study, clinicians must be cautious in generalizing these results to all sport conditions.

CONCLUSIONS

Orthotic intervention appears to be an effective means of decreasing postural sway after an isokinetic fatigue protocol. Further research may be warranted to determine whether orthotics do indeed reduce postural sway in healthy individuals and whether they are an effective means of preventing ankle injury.

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